# Southern Ocean sea ice and its wider linkages

## Sea ice impacts on climate and life

The ice reflect most of the solar radiation incident on it, contributing to keeping the region cool. It also acts as an effective insulator, restricting the exchanges of heat, mass, and momentum between the ocean and the atmosphere. This restrictions helps to preserve ocean heat in the polar winter. It also reduces wave motion and evaporation. The ice also releases salt into the ocean, increasing salinity and density of the water directly under the ice.

Sea ice also impacts various plants and animals. It houses many microorganisms, serves as a platform for larger animals such as seals and penguins, restricts light to life forms beneath the ice, and insulates life beneath the ice. The sea ice organisms and their impact on algal blooms and primary productivity in turn impact animals all the way up through the food chain.

* Importance of microorganism to the foodchain is likely relevant here, there are references in the text however it is likely worth also looking up further sources.
* Discussion around the importance of these microorganisms could lead to the importance of understanding how they form/grow and what impacts this. There is a lot in the next paper surrounding this. It also leads to the need for the PAR measurement system.

## Global impacts of sea ice

With some preamble here about positive feedback within the sea ice system, the impact of sea ice concentration changes is, on average, to warm the surface air by 0.107 K for each 10% ice concentration decrease. This shows the importance of sea ice, more figures to quote within the text.

# Southern Ocean Biogeochemical Argo detect under-ice

# phytoplankton growth before sea ice retreat

Previously, it was hypothesized that algal blooms are observed in the wake of the receding ice edge. Implying that prior to the release of meltwaters, growth rates remain low, only increasing substantially in response to melting. Current studies focus mainly on the spring and summer seasons, and most of the current literature is based on studies of Arctic under-ice phenology. However, Antarctic sea ice is distinct from that of the Arctic as it is generally thinner and more dynamic, and has much more snow year round that does not form melt ponds. From the previous studies, it is also seen that the characteristics of the Southern Ocean are distinct from those of the Arctic… and that data/conclusions drawn from Arctic experiments do not necessarily extend to the Antarctic.

It was found that only 10% of the events occurred at the same time or after the sea ice retreat. Meaning that 90% of the events preceded the ice melt. Given that the definition of GI is rather conservative, it is likely that growth is increasing earlier than calculated(?).

The paper finds that phytoplankton are able to sustain growth long before significant freshening of the surface ocean. The release of meltwaters does not appear to relieve light and/or nutrient limitation, and so variability in melt timing cannot account for variability in GI.

The paper suggests that GI is instead correlated more strongly with latitude, suggesting that phytoplankton are responding to changing incident light conditions rather than fresh water fluxes.

## Growth under extreme light limitation

Previous studies suggest that light transmittance through typical consolidated ice would be just 1% - 5% of that incident to the surface. Two possible explanations for growth under these conditions are then apparent, one – light is more readily available in ice-covered environments than previously thought, and two – phytoplankton are more adapted to extreme low light than previously thought. Both factors are likely operating simultaneously, as the presence of growth indicates light levels above zero, suggesting a revision of our current understanding of under-ice environments.

Another important point is that while 100& sea ice cover in the winter Antarctic sea ice as seen from satellite does not necessarily imply a consolidated ice surface. While the ocean is completely covered, the ice may be unconsolidated. (Could mention the formation of ice in the southern ocean and conditions that prevent the formation of pack-ice-like conditions). Therefore, the highly dynamic nature of Antarctic sea ie may lead to a general enhancement of light availability in the underlying ocean.

\subsection{The Importance of Antarctic Research}

Antarctica and the Southern Ocean (the Antarctic) region is interconnected with the rest of the world via oceanic and atmospheric couplings, and is an intrinsic part of the Earth system \cite{SustainedAntarcticResearch}. Despite the regions importance, research in the area has been lacking, especially when compared to the research done in the Arctic. \cite{SustainedAntarcticResearch}. However, the morphology of the two regions is very different \cite{ArcticandAntarctic}. The sea ice in the Arctic Ocean is historically perennial, due to the region being relatively protected since it is mostly landlocked \cite{AntarcticSeaIce}. In contrast, the sea ice found in the Antarctic is bounded to the south by the Antarctic Continent, and exposed to the Southern Ocean to the north. This leads to most of the sea ice in the region being seasonal \cite{AntarcticSeaIce}.

Simmonds highlights the inability of climate models to accurately predict variations in the sea ice extent (SIE) in the Antarctic, as compared to the Arctic \cite{ArcticandAntarctic}. In fact, Coupled Model Intercomparison Phase 5 (CMIP5) simulations were able to correctly predict the loss of Arctic SIE, albeit conservatively with regards to the rate of loss. The same simulations also predicted a loss of Antarctic sea ice, however studies have shown a slight increase of sea ice in the Antarctic region \cite{ArcticandAntarctic}.

\subsection{Antarctic Sea Ice}

Sea ice has many vital roles within the Antarctic Region. The coverage of sea ice in the region varies from a maximum of $18.83 x 10^6 km^2$ to a minimum of $3.06 x 10^6 km^2$ \cite{ArcticandAntarctic}.

The ice keeps the region cool by reflecting most of the solar radiation incident on it \cite{SeaIceaandLinkages}.